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# Ionospheric Propagation Correction Modeling for Satellite Altimeters

**(NASA-CR-156881) IONOSPHERIC PROPAGATION  
CORRECTION MODELING FOR SATELLITE ALTIMETERS  
(EG & G Washington Analytical Services)  
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# **Ionospheric Propagation Correction Modeling for Satellite Altimeters**

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## Section 1.0

### INTRODUCTION

Propagation delay through the ionosphere is one of the error sources for which a correction must be made for future satellite altimeters, with satellite to mean sea surface height accuracies required at the few centimeter level. The maximum correction amounts to approximately 15 cm. at 14 GHz. Due to the large variations between daytime and nighttime ionospheric electron densities, a correction would be required even for precision profiling missions for which absolute height accuracy is not required.

Several approaches are possible, including measuring the correction through the use of a dual frequency altimeter, and the use of various types of ionospheric modeling. This report considers the two modeling techniques which are considered most promising for application to near real-time altimetry processing, with a recommendation made as to the technique giving superior accuracy on a global scale.

## Section 2.0

### IONOSPHERIC MODELS

Two types of ionospheric models have been proposed as a basis for making height corrections for satellite altimeter data. The basic characteristics of these two approaches are summarized below.

#### 2.1 NASA Model

The "NASA" model is an empirical worldwide model of the ionosphere, and exists in several different versions. What will be referred to here as the NASA model [1] is presently a part of the operational Goddard Trajectory and Determination System (GTDS) at Goddard Space Flight Center. An earlier version is also in operation at the Naval Surface Weapons Center at Dahlgren, Virginia.

The NASA model assumes a profile shape as shown in Figure 1. This profile includes a number of key parameters, with the maximum electron density and height of the maximum density among the most critical. Typical global maps of height of maximum density ( $H_{max}$ ) and critical frequency (corresponding to maximum electron density) are shown in Figures 2 and 3. All parameters have latitude, longitude and diurnal dependence, which are driven by daily solar flux ( $f_{10.7}$ ) values (plus averaged values over the previous year) and a set of M3000 coefficients available from NOAA/Boulder. A typical global map of total electron content, to which the ionospheric propagation correction is proportional, is shown in Figure 4.

With the input of daily flux values, this technique gives corrections which are accurate to within approximately 20-25% [2]. Since the largest ionospheric propagation correction (at 14 GHz) is ~15 cm. for a maximum solar activity period, the NASA model errors could reach 4 cm. For less than peak solar activity, the error would be considerably smaller and the RSS error would probably be on the order of 1-2 cm. even for maximum solar activity, since nearly half of an average pass would be in nighttime for which the correction error is near zero.

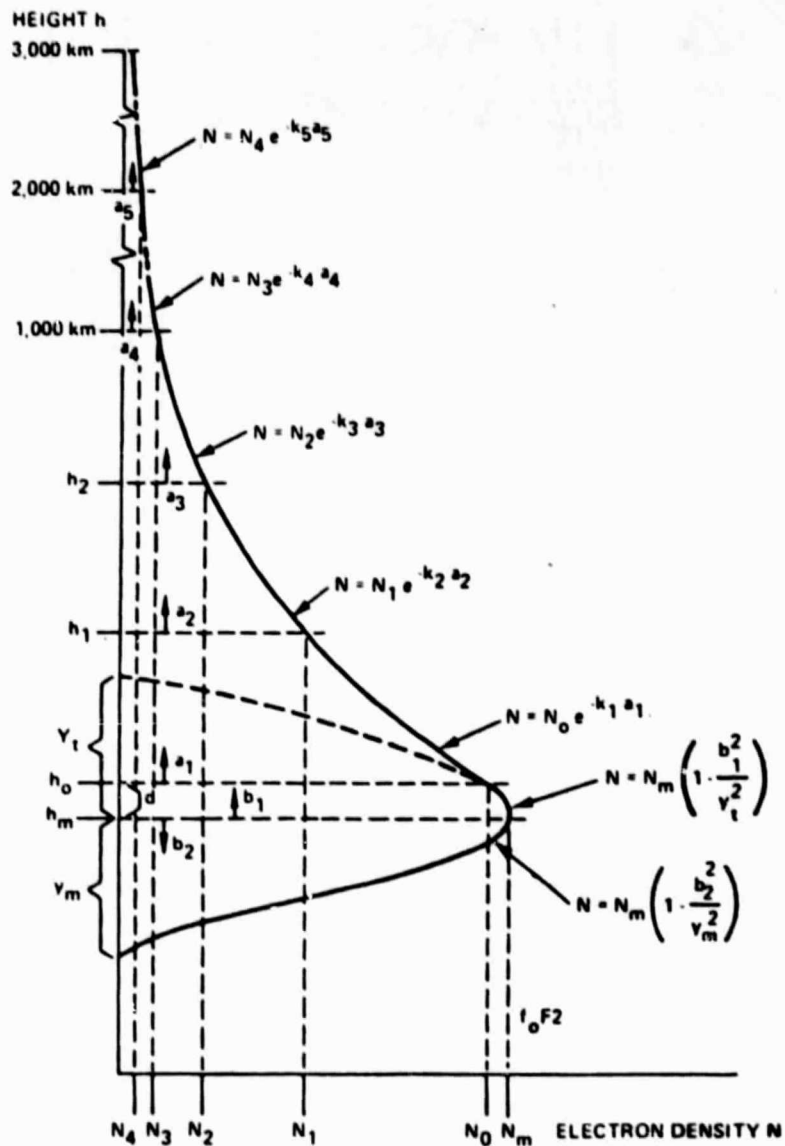


Figure 1. The Exponential, Parabolic and Bi-Parabolic Ionospheric Profile Used as a Basis for the NASA Ionospheric Model

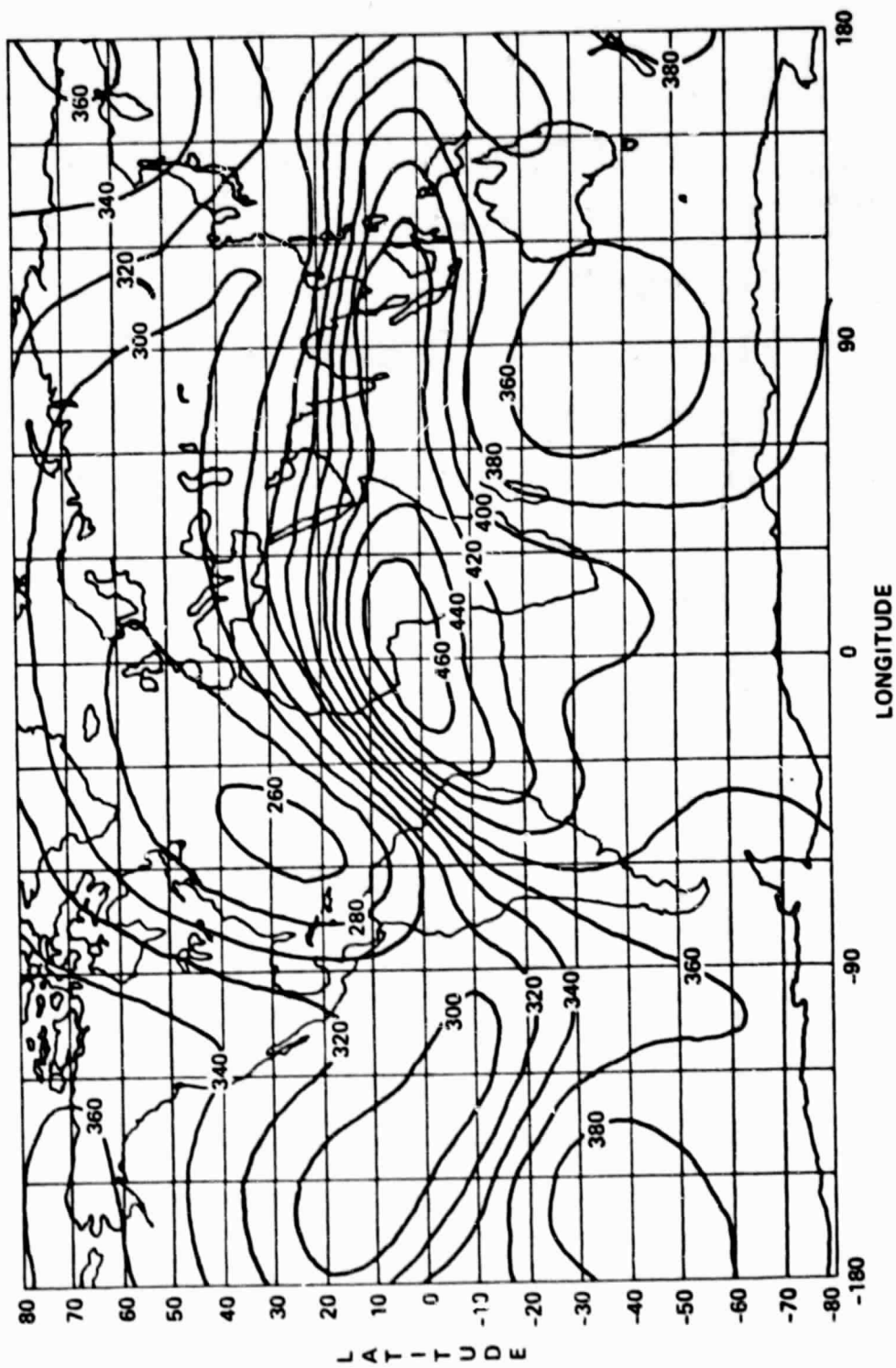


Figure 2. World Map of Height of Maximum Ionospheric Electron Density  
H<sub>max</sub> at 12 h U.T. on January 15, 1969. Contours Every 20 km.



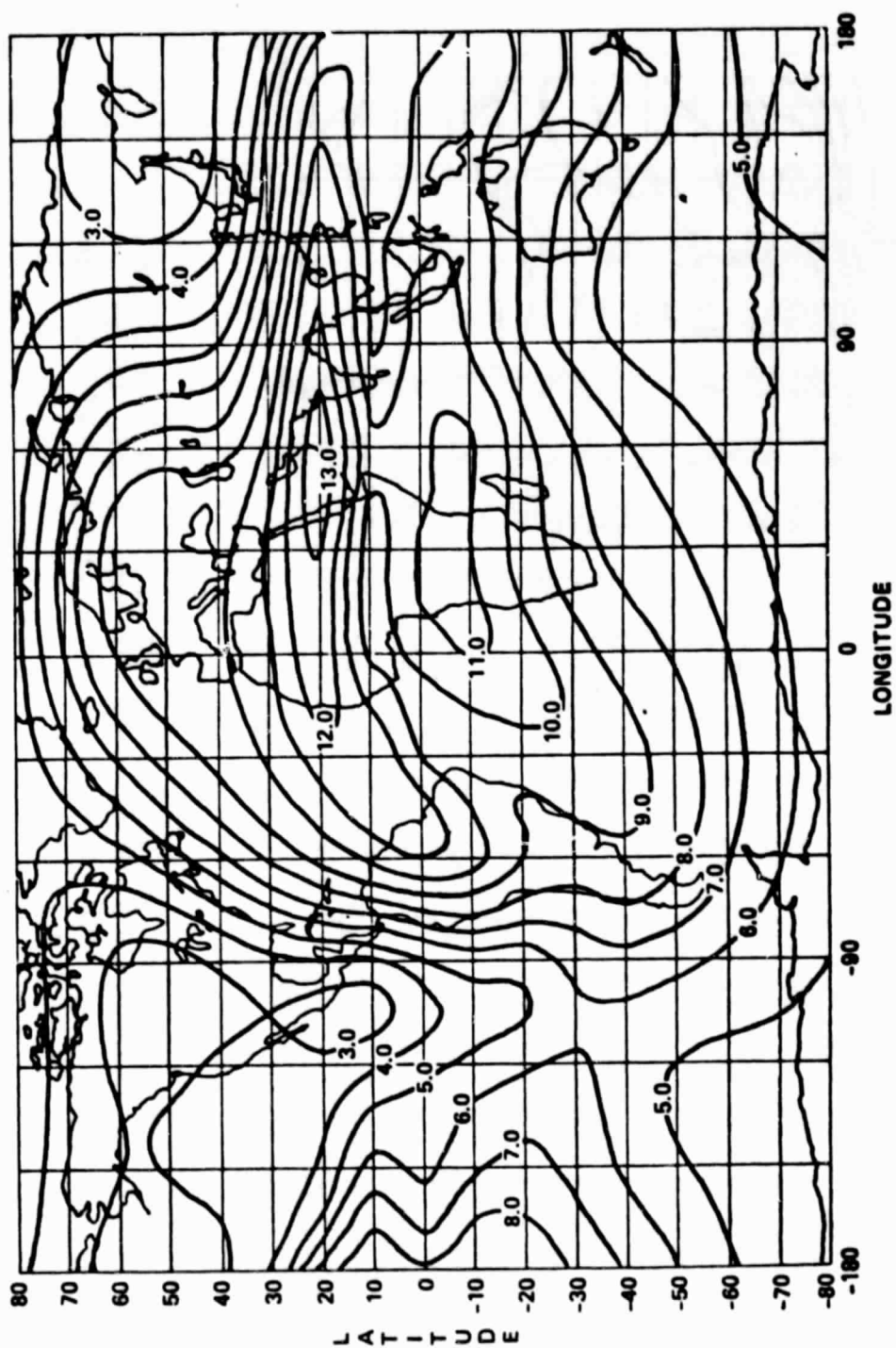


Figure 3. World Map of Ionospheric Critical Frequency  $f_oF_2$  in MHz at 12 h U.T. on January 15, 1969. Contours are Plotted Every 1.0 MHz.

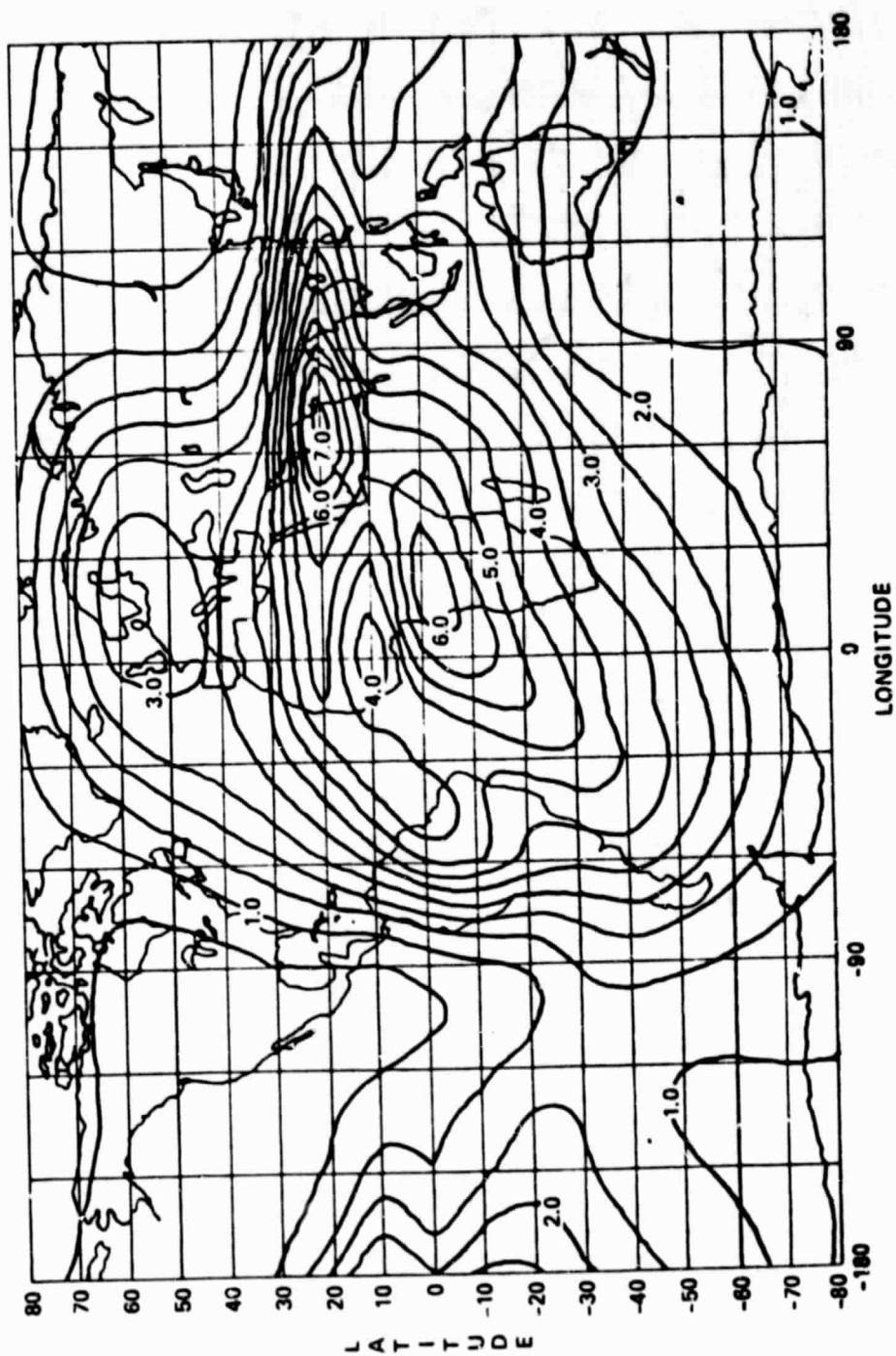


Figure 4. World Map of Integrated Vertical Electron Content N as predicted by NASA Ionospheric Model in Units of  $10^{17}$  el/sq. meter at 12 h U.T. on January 15, 1969. Contours Every  $5 \times 10^{16}$  el/sq.m.

## 2.2 JPL Faraday Rotation Model

The Faraday Rotation or "JPL" model has been used at the Jet Propulsion Laboratory, Pasadena, California. It is based on measured Faraday rotation measurements from one or more ground stations to a satellite. These measurements can then be converted to integrated electron density measurements along the slant range from the ground station to the satellite (outside the ionosphere). These measurements are then extrapolated [3] to other parts of the world as functions of time, spacecraft geomagnetic latitude, and local solar zenith angle. In the implementation of this model for Seasat altimeter data corrections [3], two ground stations were used, Armidale, Australia for the southern hemisphere and Goldstone, California for the northern hemisphere (both stations using the ATS 1 satellite).

Based on various comparisons made during Seasat data evaluation, including comparisons with corrections computed from the dual-frequency Geosceiver data, the accuracy of the Faraday Rotation method has been estimated [3] to be 3 cm. The corrections are, of course, very good near the measured ionospheric path but can have errors on the order of 50% at geographical locations far from the measurements.

### Section 3.0

#### MODEL RECOMMENDATION

Of the models discussed in the previous section, the NASA solar flux model\* is recommended for the following reasons:

1. Since the ionosphere is a highly variable and inhomogeneous medium, it does not extrapolate well beyond about 800 km. [4]. Thus, a limited set of Faraday rotation measurements is not sufficient to provide corrections on a global basis with as high degree of accuracy as can be obtained from the global empirical model.

2. Should something happen to the Faraday rotation data flow, the extrapolation technique then degrades rapidly. The global model, even without solar flux updates, degrades much more slowly.

\* The author would like to acknowledge that he is hardly an unbiased observer with regard to ionospheric models, having been deeply involved in the development of what is referred to here as the NASA ionospheric model. It is believed, however, that the arguments and evidence in support of the empirical modeling approach are overwhelming.

## Section 4.0

### IMPLEMENTATION AND CHECKOUT OF NASA MODEL

The NASA model in the GTDS program already contains the NOAA K3000 coefficient set. These coefficients consist of 36 sets of coefficients, each covering a 10 day time span, and have had seasonal and solar flux dependency removed. They are thus permanent coefficients and need not be periodically replaced. In operation, the data set is stored on disk, with only a limited set read into core as needed.

The model is currently operated as a subroutine and its implementation as a part of another system would require the removal of some linkage with GTDS. But the subroutine package is largely self-contained and the required modifications should be relatively minor.

Model maintenance requires that daily solar flux values be continually provided. As previously indicated, a set of values for the previous year is required.

Although the NASA model presently makes corrections for non-vertical paths and for angle as well as ranging measurements, there would be minimal improvement in efficiency or reduction in core requirements by making the program correct only altimeter data. It is thus recommended that the program be used basically as is (and as a black box). Extensive checkout of a transferred program could be made through comparisons of intermediate printout of the various critical parameters, as well as the computed corrections, and comparison with computed quantities on the base computer.

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